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COMPLIANCE OF A THREE-POINT BEND SPECIMEN AT LOAD LINE

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Load-line displacement information for the three-point bend specimen is presented and compared with information from the literature, with emphasis on the needs of those performing fracture tests.

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INTRODUCTION

The three-point bend specimen is often used, being one of the geometries utilized in notched bar impact and both K_{Ic} and J_{Ic} fracture toughness testing. However, comparatively little information has been published on some aspects of the load-line displacement of the specimen. The purpose here is to compare some of the available information, with emphasis on experimental needs.

DISCUSSION

For a rectangular specimen loaded in three-point bending (load P, span S, width W, thickness B, and crack length a), the load-line displacement, δ, consists of the following three terms (ref 1):

$$\delta = \delta_{bend} + \delta_{shear} + \delta_{crack} \tag{1}$$

where δ_{bend} and δ_{shear} are the bending and shear displacements of the uncracked specimen and δ_{crack} is the displacement due only to the crack. Expressions for the uncracked displacements are (ref 2):

$$\delta_{bend} = PS^3/4BW^3E \tag{2}$$

$$\delta_{shear} = 0.6(1+\nu)PS/BWE = 0.78\ PS/BWE \tag{3}$$

for $\nu = 0.3$; ν is Poisson's ratio, E is elastic modulus.

The displacement due to the crack, δ_{crack}, is given by Tada et al (ref 3) as:

$$\delta_{crack} = [6PS^2/4BW^2E] \cdot f(a/W) \tag{4}$$

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[1]J. H. Underwood, J. A. Kapp, and M. D. Witherell, "Fracture Testing with Arc Bend Specimens," Submitted to Seventeenth National Symposium on Fracture Mechanics, Albany, NY, 7-9 August 1984.
[2]R. J. Roark, Formulas for Stress and Strain, McGraw-Hill, 1965.
[3]H. Tada, P. C. Paris, and G. R. Irwin, The Stress Analysis of Cracks Handbook, Del Research Corp., Hellertown, PA, 1973.

Substituting Eqs. (2) through (4) in Eq. (1) and rearranging, the total compliance at load line can be given by:

$$EB\delta/P = S^3/4W^3 + 3.12S/4W + 6S^2/4W^2 \cdot f(a/W) \qquad (5)$$

Equation (5) is in a general form which shows the relative importance of the various components of load-line displacement, as well as the large effect of span-to-width ratio, S/W, on displacement. Equation (5) can be used to take account of specimen dimension variations on displacement. Although there is some change (ref 3) of f(a/W) with S/W, it is not significant compared with the direct effects of S/W on EBδ/P as shown by Eq. (5). For S/W = 4 the function f(a/W) in the third term of Eq. (5) is given by Tada et al (ref 3) as follows, accurate to within one percent for $0 < a/W < 1.0$:

$$f(a/W) = [a/W/(1-a/W)]^2[5.58 - 19.57\,(a/W) + 36.82\,(a/W)^2 - 34.95\,(a/W)^3 + 12.77\,(a/W)^4] \qquad (6)$$

Table I shows a comparison of the compliance values of Eq. (5) with those of ASTM Method E-813-81 (ref 4) for S/W = 4. The compliance values given in E-813 in a tabular form cover a range of a/W from 0.5 to 0.7 and do not account for the shear displacement of the uncracked specimen (ref 5). Because of this, the values of E-813 are from 6.3 percent to 1 percent below those of Eq. (5) for a/W from 0.5 to 0.7, respectively. When the shear component of

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[3] H. Tada, P. C. Paris, and G. R. Irwin, The Stress Analysis of Cracks Handbook, Del Research Corp., Hellertown, PA, 1973.

[4] "Standard Test Method for J_{Ic}, A Measure of Fracture Toughness," ASTM E-813-81, 1983 Annual Book of ASTM Standards, Vol. 03.01, American Society for Testing and Materials, 1983, pp. 762-780.

[5] J. G. Merkel, R. G. Berggren, and W. J. Stelzman, "Compliance and Fracture Toughness Calculations for Notched Bend Specimens," HSST Quarterly Progress Report, ORNL Report TM-4805, Vol. 2, March 1975.

displacement, described by Eq. (3), is added to the values of E-813, the agreement between these modified values and those of Eq. (5) is within 0.5 percent for all values of a/W.

An inverse compliance expression can be obtained from Eqs. (5) and (6) for S/W = 4, as follows:

$$a/W = 0.997 - 3.58\ U - 1.51\ U^2 - 110\ U^3 + 1232\ U^4 - 4400\ U^5 \tag{7}$$

where

$$U = 1/[(EB\delta/P)^{1/2} + 1]$$

Equation (7) was found to be accurate within less than 0.2 percent to the values from Eq. (5) over a wide range of a/W, from 0.3 to 0.945.

CONCLUSION

The results described here, as summarized in Eqs. (5) and (7), are suitable for general use in fracture testing using the three-point bend specimen, including unloading compliance J_{Ic} tests and fatigue crack growth rate tests.

REFERENCES

1. J. H. Underwood, J. A. Kapp, and M. D. Witherell, "Fracture Testing with Arc Bend Specimens," Submitted to Seventeenth National Symposium on Fracture Mechanics, Albany, NY, 7-9 August 1984.
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5. J. G. Merkel, R. G. Berggren, and W. J. Stelzman, "Compliance and Fracture Toughness Calculations for Notched Bend Specimens," HSST Quarterly Progress Report, ORNL Report TM-4805, Vol. 2, March 1975.

TABLE I. LOAD-LINE COMPLIANCE VALUES FOR THREE-POINT

BEND SPECIMEN WITH S/W = 4

a/W	$EB\delta/P$ (Eq. 5)	a/W	$EB\delta/P$ (Ref. 4)	$EB\delta/P$ (Eq. 5)	a/W	$EB\delta/P$ (Eq. 5)
0.300	28.742	0.500	50.09	53.455	0.705	155.528
0.305	29.083	0.505	51.312	54.537	0.710	160.952
0.310	29.432	0.510	52.38	55.656	0.715	166.660
0.315	29.791	0.515	53.37	56.812	0.720	172.671
0.320	30.159	0.520	54.80	58.006	0.725	179.009
0.325	30.536	0.525	55.87	59.241	0.730	185.697
0.330	30.924	0.530	57.06	60.518	0.735	192.762
0.335	31.322	0.535	58.30	61.839	0.740	200.235
0.340	31.731	0.540	59.81	63.206	0.745	208.146
0.345	32.150	0.545	61.25	64.620	0.750	216.532
0.350	32.582	0.550	62.61	66.084	0.755	225.433
0.355	33.025	0.555		67.599	0.760	234.892
0.360	33.480	0.560	64.14	69.169	0.765	244.958
0.365	33.948	0.565	65.60	70.795	0.770	255.686
0.370	34.429	0.570	67.37	72.479	0.775	267.135
0.375	34.923	0.575	69.21	74.225	0.780	279.374
0.380	35.432	0.580	72.65	76.036	0.785	292.477
0.385	35.954	0.585	74.54	77.913	0.790	306.530
0.390	36.492	0.590	76.67	79.861	0.795	321.630
0.395	37.046	0.595	78.78	81.883	0.800	37.883
0.400	37.615	0.600	80.46	83.982	0.805	355.413
0.405	38.202	0.605	82.88	86.162	0.810	374.360
0.410	38.805	0.610	84.715	88.427	0.815	394.883
0.415	39.426	0.615	87.06	90.781	0.820	417.163
0.420	40.066	0.620	89.70	93.229	0.825	441.411
0.425	40.725	0.625	92.68	95.776	0.830	467.866
0.430	41.404	0.630	95.114	98.426	0.835	496.808
0.435	42.103	0.635	97.408	101.185	0.840	528.562
0.440	42.824	0.640	100.264	104.060	0.845	563.506
0.445	43.567	0.645	104.26	107.056	0.850	602.085
0.450	44.332	0.650	107.13	110.179	0.855	644.822
0.455	45.122	0.655	110.40	113.439	0.860	692.340
0.460	45.936	0.660	113.53	116.841	0.865	745.378
0.465	46.776	0.665	117.08	120.395	0.870	804.826
0.470	47.642	0.670	121.10	124.109	0.875	871.757
0.475	48.535	0.675	125.00	127.994	0.880	947.479
0.480	49.458	0.680	128.72	132.059	0.885	1033.591
0.485	50.410	0.685	132.97	136.317	0.890	1132.076
0.490	51.392	0.690	137.80	140.778	0.895	1245.403
0.495	52.407	0.695	141.29	145.458	0.900	1376.687
		0.700	146.97	150.369		

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